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THE WEATHERING OF PLASTIC
MATERIALS IN THE TROPICS

3. THE EVALUATION OF A SOLAR RADIATION
CONCENTRATION DEVICE (EMMA) AS A MEANS OF
ACCELERATING THE WEATHERING OF PLASTICS

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Report by

Procurement Executive, Ministry of Defence/British
Plastics Federation Joint Committee on the Behaviour
of Plastics Materials under Tropical Conditions

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Propellants, Explosives and Rocket Motor Establishment
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FOREWORD

Since 1948 a joint endeavour has been pursued by Government Agencies and the British Plastics Federation to determine the behaviour of plastics materials when exposed to outdoor conditions in the tropics. Until the late 1950's, tropical ageing was carried out by the Tropical Testing Establishment, Port Harcourt, Nigeria and a series of reports 'Plastics in the Tropics' published by Her Majesty's Stationery Office was issued during the period 1951 to 1962.

Following the closure of the Tropical Testing Establishment, the Joint Tropical Research Unit (JTRU) was established at Innisfail, Queensland, Australia in 1962 with equal participation of the Australian Department of Supply and the United Kingdom Ministry of Aviation. Trials have been sponsored since this time under the successive auspices of the Ministry of Aviation, the Ministry of Technology, the Ministry of Aviation Supply and, recently, the Ministry of Defence (Procurement Executive). The first two of the new series of reports on Plastics in the Tropics (dealing with polycarbonate and polyacetal) have been published recently.

The following report was written in 1974. Until now it has remained an internal committee report. As a result of assessing these results it was decided to perform a second exposure trial similar to the one reported on here to verify the findings and provide additional information. This second trial is now completed and a report will be issued shortly.

1 INTRODUCTION

The Joint Sub-Committee initiated a trial of limited scope to assess the claims made for 'accelerated natural weathering' by Desert Sunshine Exposure Tests Inc of Phoenix, Arizona, who have developed systems for increasing the intensity of solar radiation falling on test specimens.

Phoenix receives on average more than 4000 hours sunshine a year (compared with the UK range of 1000 - 1400). It is located at Lat $33^{\circ}30'N$, Long $12^{\circ}3'W$ at an altitude of 2000'. At the Desert Sunshine Exposure Test site the intensity of the sunshine which falls on samples exposed on the static exposure racks (45° facing South) can be increased by using equatorial mounts which present the test samples normally to the sun throughout the day. A still further intensification of radiation is available on the device known as EMMA (Equatorial Mount with Mirror for Acceleration) where the sun-following facility of the equatorial mount is augmented by means of mirrors of high reflectivity so that test specimens receive about nine times the total solar radiation that they would in a static rack.^{3,4} With this device, excessive heat build-up is claimed to be avoided by blowing air over the samples. In addition a facility is available for spraying specimens with water at intervals; however this was not used in the present trial.

The materials selected for this trial were low density polyethylene, and polyacetal copolymer, for which weathering data are already available from previous trials.^{2,5,6} The "natural" polymers, without any ultra violet light absorbing additives were used as these were expected to show signs of degradation after relatively short terms of static exposure. The trial began using both EMMA and the static racks (45° facing South) in Phoenix as laid down in the trial schedules (Appendices 1 and 2). At the end of each exposure period, specimens were returned to the Explosives Research and Development Establishment (ERDE)* for physical testing.

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2 EXPERIMENTAL

2.1 Materials

Two materials were used, low density polyethylene, and polyacetal copolymer, both of commercial origin. The materials and their source are specified in Table 1.

TABLE 1

Polymer	Trade Name	Grade and Colour	Supplier	Additives
Polyethylene (Low Density)	Alkathene	WJG11 Natural	ICI	0.2% N,N'-bis(2-naphthyl-1,4-diaminobenzene)*
Acetal Copolymer	Alkon (Kematal)	M90-02	ICI	Undisclosed

2.2 Specimens

2.2.1 Polyethylene Specimens

Polyethylene sheet was compression moulded at ERDE to a nominal size of 180 x 130 x 1.5 mm. Following exposure of these sheets, 5 dumb-bells were cut from each, with a cutter meeting the requirements of BS 903 Part A2 (Type E). (Figure 1c.)

2.2.2 Polyacetal Specimens

Dumb-bells were injection moulded to an ERDE design⁷ (Figure 1a) and had a nominal thickness of 3.2 mm ($\frac{1}{8}$ inch). The notched tensile specimens were machined from injection moulded bars. (Figure 1b.)

2.3 Exposure

2.3.1 Test pieces and sheets were exposed in Phoenix on static racks at 45° to the horizontal facing south for withdrawal after 3, 6 and 12 months exposure.

*NN'-di-2-naphthyl-p-phenylene diamine (DNPD) (see BS 2,82 Method 405B).

2.3.2 Corresponding specimens were simultaneously exposed at the same site on EMMA for withdrawal after 1, 2, 4, 8 and 16 weeks exposure.

2.4 Conditioning Before Test

Before mechanical testing was undertaken, specimens were conditioned for 28 days at $20^{\circ} \pm 2^{\circ}\text{C}$ and $65 \pm 5\%$ relative humidity. Unexposed specimens were tested at the beginning of the trial. However insufficient material was available for the testing of stored unexposed specimens at the end of the trial.

2.5 Test Methods

2.5.1 Visual Assessment

Specimens were assessed for colour change, loss of gloss, cracking and chalking.

2.5.2 Mechanical Properties

2.5.2.1 General

Measurements were generally made on 5 replicates. In some instances however samples were broken in transit thus reducing the number of replicates available. Testing was carried out under the standard conditions mentioned in 2.4.

2.5.2.2 Tensile Stress and Elongation at Break

Dumb-bells were measured to determine the mean cross-sectional area of the parallel part, and were tested using a Monsanto Tensometer 'E' Type N100, at 0.42 mm s^{-1} (1 in min^{-1}) crosshead rate of travel.

Elongations below 10% were measured with an Instron 1" extensometer, elongations above 10% were obtained from the autographic record. Stresses at yield and at break were calculated on the cross-sectional area of the specimen at the start of the test.

2.5.2.3 Notched Tensile Strength

Specimens were strained at a crosshead rate of 0.42 mm s^{-1} (1 in min^{-1}). The maximum stress recorded was based on the original cross-sectional area between the apices of the notches.

2.6 Meteorological Data

Temperature, rainfall, relative humidity and hours of sunshine were measured daily in accordance with standard meteorological practice. Records of total solar radiation (Langleys) were provided by the Phoenix organisation for both EMMA and the static exposure racks.

3 RESULTS

3.1 Exposure Conditions

The meteorological data for the Phoenix site and the total solar radiation received by specimens on the static racks and on EMMA are tabulated in Appendix 3. From these it will be seen that the specimens on EMMA received about $9\frac{1}{2}$ times the radiation received by specimens on the static racks, which is in reasonable agreement with the factor claimed.^{3,4}

3.2 Visual Assessment

Both the LD polyethylene and the acetal copolymer changed in appearance during exposure, the polyethylene losing its gloss and developing cracks, and the polyacetal losing its gloss and ultimately chalking severely. The cracks in the polyacetal were restricted to the notched tensile specimens and confined to the area of the notch. During exposure the polyethylene specimens became pinkish-brown in colour on the 45° racks and EMMA. In addition, towards the end of the trial, specimens on the 45° racks exhibited a velvety bloom.

The results are given in full in Appendix 4.

3.3 Tensile Strength and Elongation at Break

The full results for these two properties are given in Appendices 6 and 5. Tables 2 and 3 show median values, and these results are plotted in Figures 2 - 6.

Figures 7 and 8 present the tensile data for polyethylene exposed on EMMA and the static racks respectively. The behaviour at yield and at break for all of the exposure periods are presented together graphically so that the change in behaviour with time can be clearly seen.

TABLE 2

Material	Exposure	Period (weeks)	Yield Stress Mega Pascal	Breaking Stress Mega Pascal
LD Polyethylene	Control	0	8.10	12.17
	EMMA	1	8.10	12.17
		2	7.93	9.03
		4	8.89	9.76
		8	Did not yield	8.69
		16	" " "	6.96
	45°	13	8.62	8.20
	facing	26	Did not yield	9.03
	South	52	" " "	8.60
Acetal Copolymer	Control	0	Did not yield	63.4
	EMMA	1	Did not yield	61.7
		2	" " "	57.6
		4	" " "	50.0
		8	" " "	31.5
		16	" " "	8.55
	45°	13	Did not yield	38.4
	facing	26	" " "	34.0
	South	52	" " "	21.7

TABLE 3

Material	Exposure	Period (weeks)	Elongation at Yield	Elongation at Break (%)
LD Polyethylene	Control	0	21	538
	EMMA	1	42	610
		2	90	420
		4	90	460
		8	Did not yield	71
		16	" " "	35
	45° facing South	13	40	130
		26	Did not yield	67
		52	" " "	57
Acetal Copolymer	Control	0	Did not yield	4.5
	EMMA	1	Did not yield	3.2
		2	" " "	2.6
		4	" " "	1.5
		8	" " "	1.5
		16	" " "	0.5
	45° facing South	13	Did not yield	0.7
		26	" " "	0.8
		52	" " "	1.2

3.4 Notched Tensile Strength

The notched tensile results for polyacetal are given in full in Appendix 6, and are summarized in Table 4 and plotted in Figure 6.

TABLE 4

Material	Exposure	Period (weeks)	Notched tensile strength (N mm ⁻²)
Acetal Copolymer	Control	0	54.1
	EMMA	1	37.3
		2	37.7
		4	27.9
		8	21.0
		16	19.3
	45° facing South	13	28.0
		26	26.2
		52	20.7

4 DISCUSSION

4.1 Visual Assessment

The absence of bloom on the LD polyethylene, and the absence of colour change with the acetal copolymer when both of these were exposed on EMMA, requires explanation. Polyethylene showed a colour change on the 45° racks and EMMA as a result of exposure. This is a well-known phenomenon due to the migration to the surface of the particular antioxidant used. However the blooming of the polyethylene specimens and the colour changes occurring with the polyacetal specimens were confined to specimens on the 45° racks. It is probably that these changes did not occur with the accelerating unit because insufficient time was allowed for their development.

4.2 Mechanical Properties

The major changes in tensile strength and elongation at break in polyethylene and polyacetal exposed on the 45° racks occurred during the first exposure period. On EMMA, on the other hand, the choice of exposure periods provided a more informative picture of the changes in these properties with time. In order to more satisfactorily compare the respective behaviour patterns under the two modes of exposure and predict an acceleration factor, earlier withdrawals from the 45° racks would have been necessary. For example,

Figure 7 clearly shows the progressive embrittlement of the polyethylene as exposure on EMMA proceeds. This is indicated by the loss of elongation until, after 8 weeks exposure, there is no yield point at all. It is equally clear from Figure 8 that for exposures on the static racks a better comparison with Figure 7 would have been obtained if withdrawals had been made at periods shorter than 13 weeks.

The same criticisms can be levelled at the choice of exposure periods for the notched tensile specimens of polyacetal.

It appears, however, that the rate of loss of mechanical properties on EMMA was at least twice as great as that on the 45° racks.

5 CONCLUSIONS

(i) In this trial polyacetal copolymer and LD polyethylene specimens were exposed to the weather on static racks in Arizona and their behaviour compared with the behaviour of similar specimens exposed on the accelerated weathering unit, EMMA, at the same site. It was found that similar changes in mechanical properties occurred and the effects were produced in samples exposed on EMMA at least twice as fast as in those exposed on the 45° racks.

(ii) In the case of changes in appearance, however, the similarities in behaviour were less marked; specimens exposed on the 45° racks exhibited effects which were not reproduced on EMMA within the time scale of the trial. It is probable that the exposure time on EMMA was too short for these effects to become apparent.

(iii) Because the first exposure period on the 45° racks was rather too long for the rate of degradation which occurred, no firm quantitative comparison can be made between the two modes of exposure.

(iv) Hence, if on consideration a better quantitative comparison is required, a further trial will be necessary.

6 ACKNOWLEDGEMENTS

The assistance of the staff of Materials Research Branch, MOD, MVEE, Christchurch, Hants in supplying specimen holders and arranging exposure at Phoenix and of ERDE* Waltham Abbey in carrying out the physical testing, is gratefully acknowledged.

*Now PERME

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- 3 US Patent 2.945.417, 1960.
- 4 IEC Prod Res & Dev 1. No 4 (Dec No 2) 248-253.
- 5 Ministry of Aviation. ERDE Technical Memorandum 2/JTRU/60.
- 6 Ministry of Supply. TTE Unpublished Report.
- 7 Hazell E A. Composites, Dec 1970.
- 8 Baum G A. Weatherability of Plastics Materials, Interscience, 1964 (1967).
- 9 Official Digest, 34, 1017 (1962).
- 10 Private Communication ICI Plastics Division to ERDE.

Desert Sunshine Exposure Site

Phoenix, Arizona

Schedule of Trial

Subject: Polythene sheet

1 Sponsor: Standing Committee on Plastics

Manufacturer: ICI

2 Purpose of Trial: To evaluate the claims made for the site and the accelerated natural weathering device EMMA.

3 Scope of Trial:

No of types	- 1
replicates	- 1
No of withdrawals	- 3 from racks, 5 from EMMA
No of sites	- 1
No of specimens on site	- 8
No as controls	- 3
	<u> </u>
Total:	11
	<u> </u>

4 Exposure: Method: (1) On racks at 45° facing South
(2) On EMMA

Specimens: 1.5 mm sheet approx 130 x 180 mm
3 to be mounted on racks at 45° facing South
5 to be mounted on EMMA

Type: Alkathene clear containing 0.2% 'Nonox' CI anti-oxidant.

5 Assessment: Tests in UK:

Yield stress and ultimate tensile strength	} 5 dumb-bells to BS 903 Type E
Elongation at break	
Power Factor	2 test specimens
Visual assessment during exposure	
density measurements	

APPENDIX 1

6	<u>Withdrawal Programme:</u>	Site:	3 months)	1 week)	EMMA exposure	
			6 months)	Natural exposure		2 weeks)
			12 months)			4 weeks)
				8 weeks)		
				16 weeks)		

Controls - beginning and end of exposure

To be sent by air to UK as soon as possible after withdrawal.

Desert Sunshine Exposure SitePhoenix, ArizonaSchedule of Trial

Subject: Polyacetal moulded test specimens

1 Sponsor: Standing Committee on Plastics

Manufacturer: ICI

2 Purpose of Trial: To evaluate the claims made for the site and the accelerated natural weathering device EMMA.

3 Scope of Trial:

No of types	- 1
replicates	- 1
No of withdrawals	- 3 from racks, 5 from EMMA
No of sites	- 1
No of specimens on site	- 8
No as controls	- 1
Total:	9
	=

4 Exposure: Method: (1) On racks at 45° facing South.
(2) On EMMA

Specimens: For the purpose of this trial one specimen will consist of 5 dumb-bell test specimens and 4 notched tensile test specimens mounted on a framework to form a module for exposure and withdrawal.

Type:

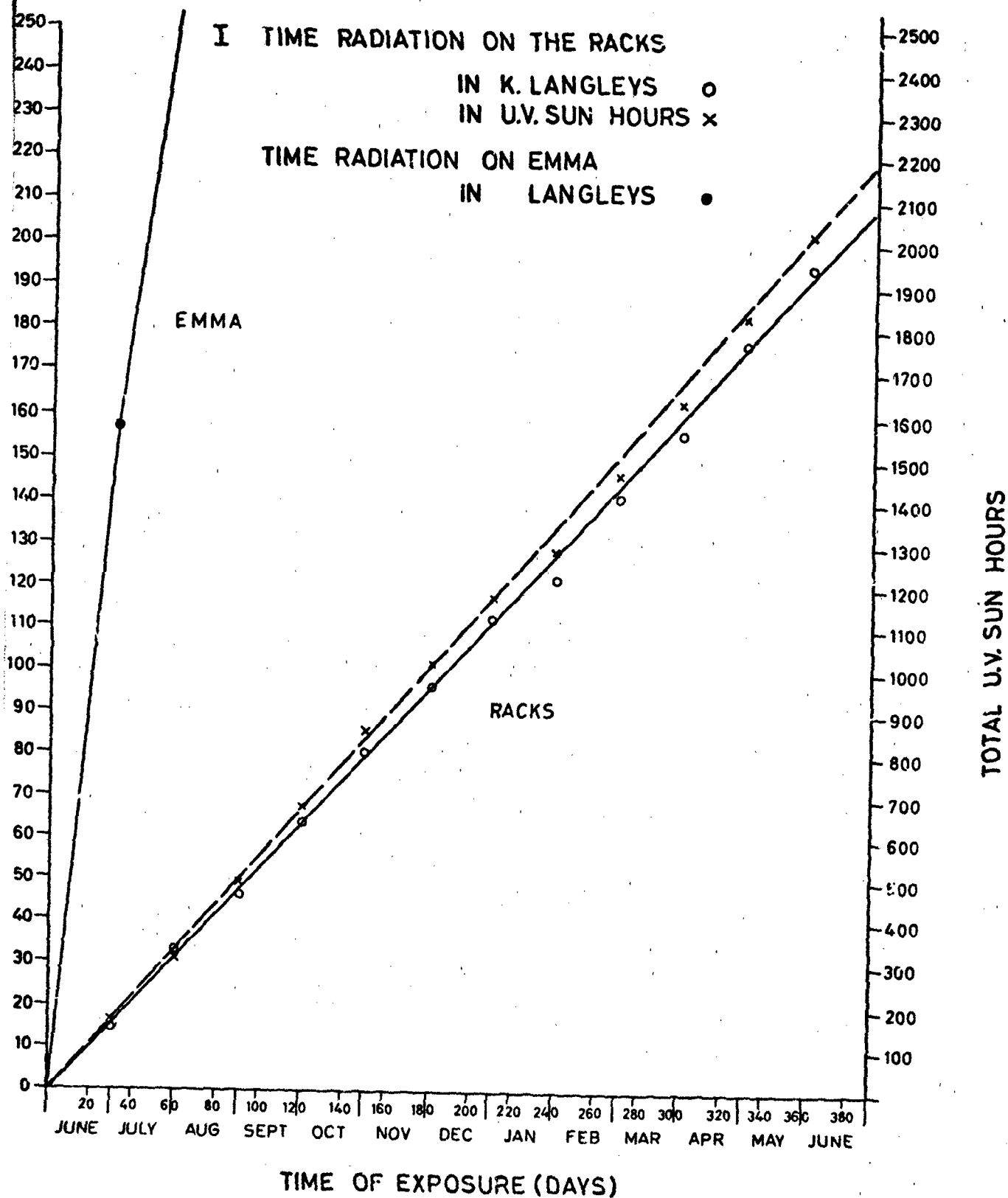
5 Assessment: Tests in UK:

Yield stress and ultimate tensile strength)	} on 5 dumb-bell specimens
Elongation at break	
Notched tensile test	4 specimens
Visual assessment	
Weighing of selected specimens	

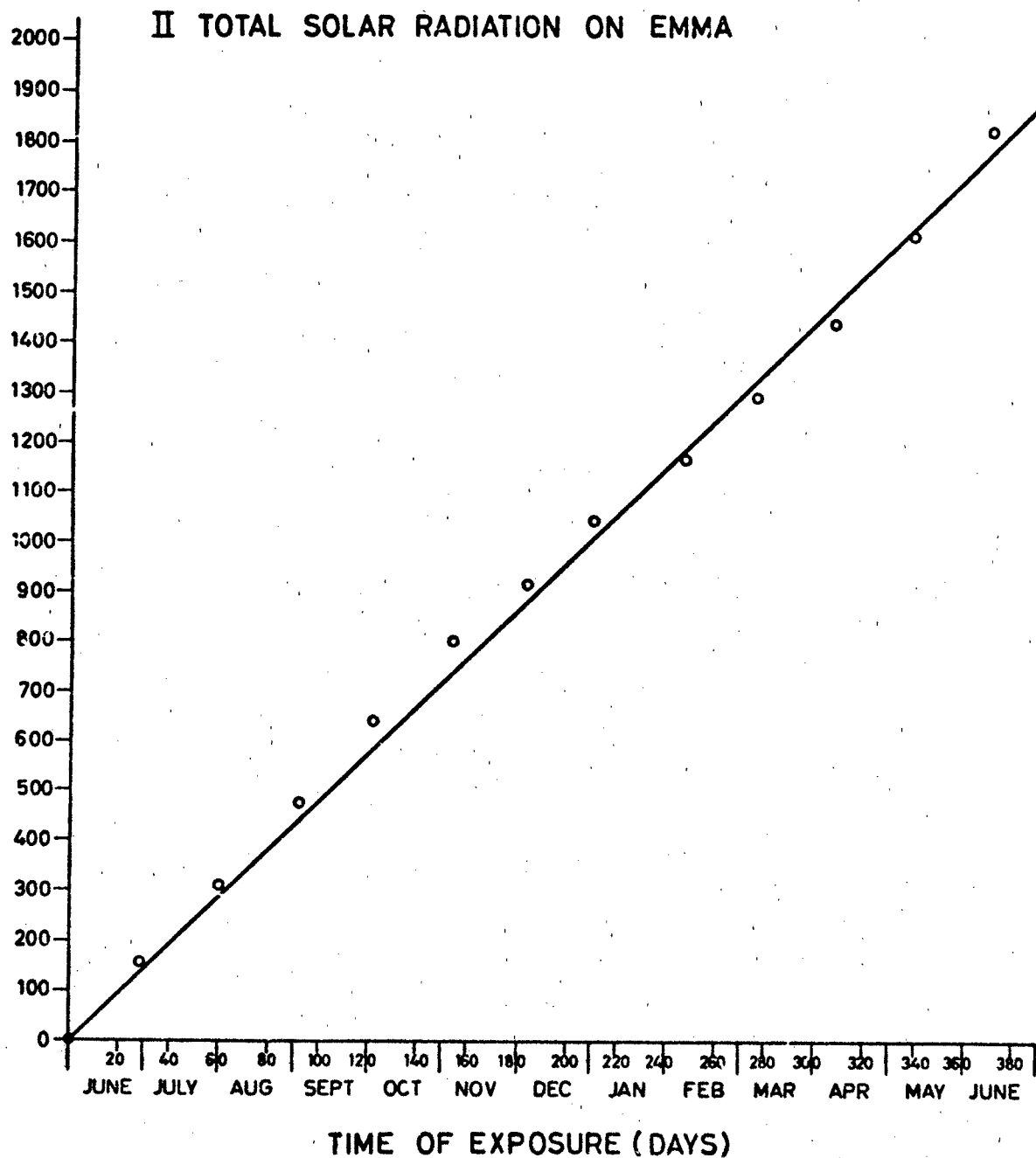
APPENDIX 2

6	<u>Withdrawal Programme:</u>	Site:	3 months)	1 week)
			6 months) Natural	2 weeks)
			12 months) exposure	4 weeks) EMMA
				8 weeks) exposure
				16 weeks)

To be sent by air to UK as soon as possible after withdrawal.



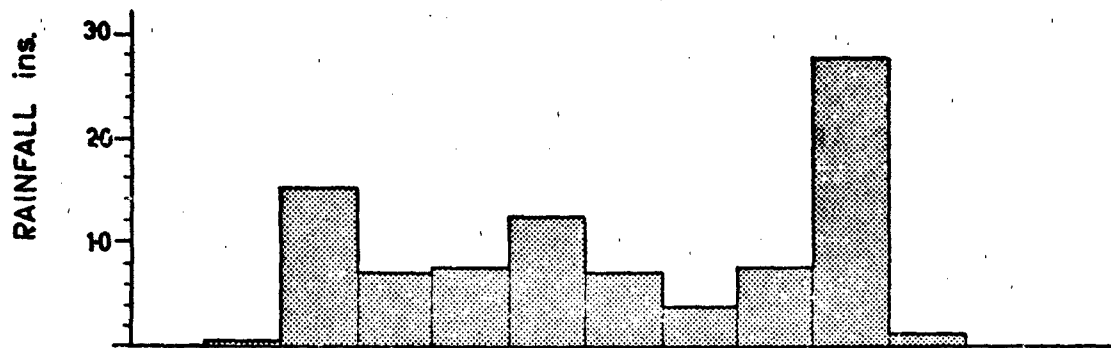
METEOROLOGICAL DATA FOR PHOENIX, ARIZONA



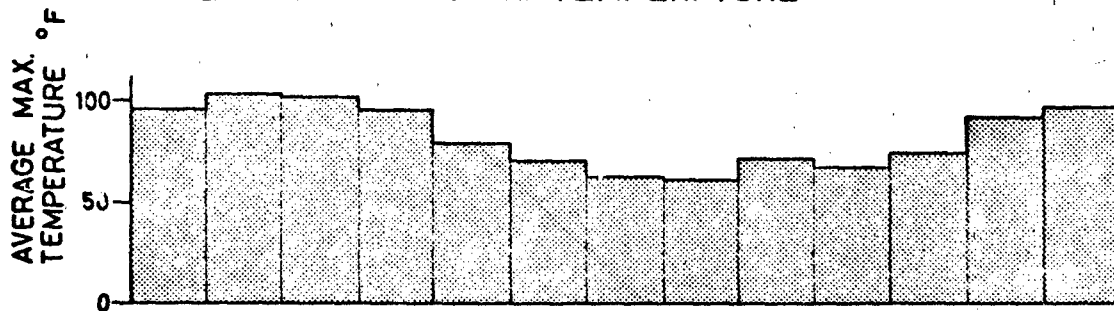
METEOROLOGICAL DATA FOR PHOENIX, ARIZONA

III RAINFALL

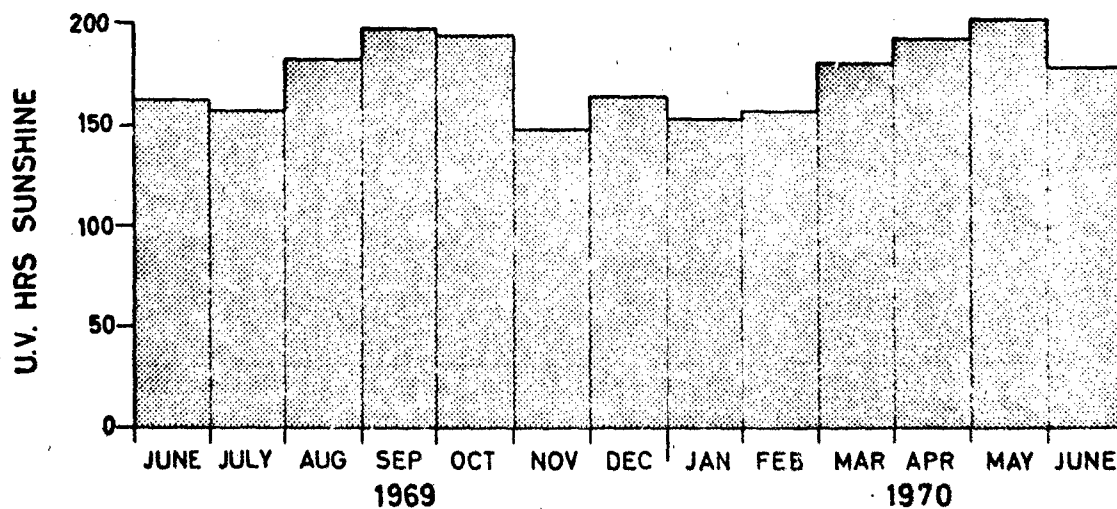
Appendix 3



IV AVERAGE MAX. TEMPERATURE



V U.V. HOURS OF SUNSHINE



METEOROLOGICAL DATA FOR PHOENIX, ARIZONA

Change in Appearance of Exposed Specimens

Rating Scale: 0 = No Change 1 = Slight Change 2 = Moderate Change
3 = Severe Change

Material	Exposure	Time (weeks)	Assessments			
			Colour Change	Loss of Gloss	Cracking	Chalking
Polythene	EMMA	1	0	1	0	0
		2	1	1	0	0
		4	3	1	1	0
		8	2	2	2	0
		16	1	2	2	0
	Static 45° to Horizontal	13	2	0	0	0
		26	1	1	1	0
		52	1 ⁺	2	2	1
Polyacetal	EMMA	1	0	0	0	0
		2	0	0	0	0
		4	0	1	0	1
		8	0	3	2*	3
		16	0	3	3*	3
	Static 45° to Horizontal	13	0	1	0	1
		26	1	3	1*	3
		52	2	3	3*	3

*At notches of notched tensile specimens only

⁺A velvety bloom observed

Individual and Median Mechanical Test Results for LD Polyethylene
(Median Results in SI Units in brackets)

Method of Exposure	Duration of exposure weeks	Total solar radn l.	Yield stress lbf/in ²	Elongation at yield %	Break stress lbf/in ²	Elongation at break %
EMMA	0	0	1090	27	1725	520
			1240	20	1765	538
			1175	21	1895	580
			1175 (8.10)	21	1765 (12.17)	538
	1	39	1175	22	1765	674
			1300	42	1895	541
			1300	42	1805	610
			1175	72	1595	630
			1175	72	1215	330
			1175 (8.10)	42	1765 (12.17)	610
	2	68	1270	90	1310	360
			1070	100	1515	610
			1200	90	1310	420
			1070	80	1070	280
			1150	80	1515	550
			1150 (7.93)	90	1310 (9.03)	420
	4	146	1240	90	1240	380
			1290	98	1550	460
			1290	90	1415	400
			1290	90	1720	520
			1150	90	1415	462
			1290 (8.89)	90	1415 (9.76)	460
	8	282	Did not yield		1355	71
					1300	63
					1260	71
					1190	71
					1255	94
					1260 (8.69)	71
	16	575	Did not yield		970	36
					980	22
					1010	39
					1040	35
					1050	24
					1010 (6.96)	35
Static 45° to horizontal facing South	13	48	1250	60	1200	238
			1240	40	1280	112
			Did not yield		1145	130
					1140	142
			Did not yield		1190	63
			1250 (8.62)	40	1190 (8.20)	130
	26	99	Did not yield		1400	-
					1310	51
					1300	71
					1310	75
					1320	63
					1310 (9.03)	67
	52	189	Did not yield		1240	32
					1265	63
					1290	52
					1052	63
					-	-
					1248 (8.60)	57

Abbreviations: l. = lumen, cal cm⁻² (41.9 kJ m⁻²)

EMMA = equatorial mount with mirror acceleration.

APPENDIX 6

Individual and Median Mechanical Test Results for Acetal Copolymers

(Median Results in SI Units in Brackets)

Method of Exposure	Duration of exposure weeks	Total solar radn L	Break stress lbf/in ²	Elongation at break %	Notched tensile stress lbf/in ²
EMMA	0	0	9200	-	7650
			9100	3.7	8050
			9500	6.6	8250
			9100	4.1	7210
			9210	4.9	-
			9200 (63.4)	4.5	7850 (54.1)
	1	39	8840	2.4	5650
			8730	2.6	5210
			9070	3.4	4870
			8950	3.2	5610
			8990	3.4	-
			8950 (61.7)	3.2	5410 (37.3)
	2	68	8390	2.3	4690
			8260	2.5	5360
			7850	1.6	5550
			8360	2.6	5670
			8680	2.6	-
			8360 (57.6)	2.6	5460 (37.7)
	4	146	7500	1.7	4000
			7250	1.5	4100
			8570	2.0	3950
			7090	1.5	5550
			7170	1.5	-
			7250 (50.0)	1.5	4050 (27.9)
	8	282	6090	1.0	3390
			4250	1.8	3050
			4100	1.0	3050
			5630	2.0	2540
			4570	1.5	-
			4570 (31.5)	1.5	3050 (21.0)
	16	575	1240	(ca 1 mm)	2800
			1360	0.5	-
			1110	0.5	-
			-	-	-
			-	-	-
			1240 (8.55)	0.5	2800 (19.3)

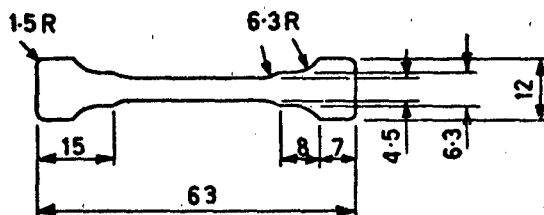
APPENDIX 6

Method of Exposure	Duration of exposure weeks	Total solar radn L	Break stress lbf/in ²	Elongation at break %	Notched tensile stress lbf/in ²
Static 45° to horizontal facing South	13	48	5470	0.7	4140
			5570	0.6	3970
			5760	0.8	4280
			4750	0.7	3760
			5710	0.8	-
			5570 (38.4)	0.7	4055 (28.0)
	26	99	5260	1.1	3880
			4930	0.8	3960
			5270	1.0	3690
			4460	0.7	3720
			4720	0.7	-
			4930 (34.0)	0.8	3800 (26.2)
	52	189	4150	1.5	3230
			3030	0.9	2770
			3150	-	-
			-	-	-
			-	-	-
			3150 (21.7)	1.2	3000 (20.7)

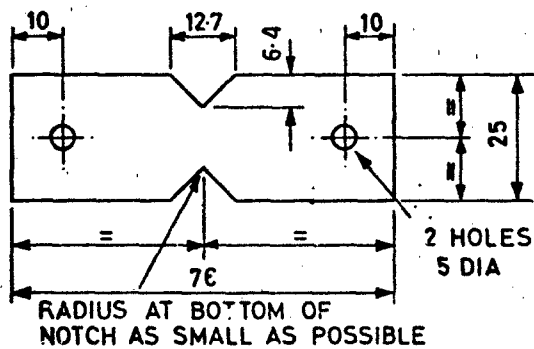
I. = Langley, cal cm⁻² (41.9 kJ m⁻²)

EWMA = equatorial mount with mirror acceleration

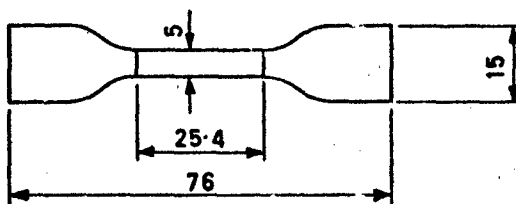
1a SMALL ERDE DUMBELL



1b NOTCHED TENSILE SPECIMEN



1c POLYETHYLENE DUMBELL



ALL DIMENSIONS IN mm

FIG 1 SPECIMENS

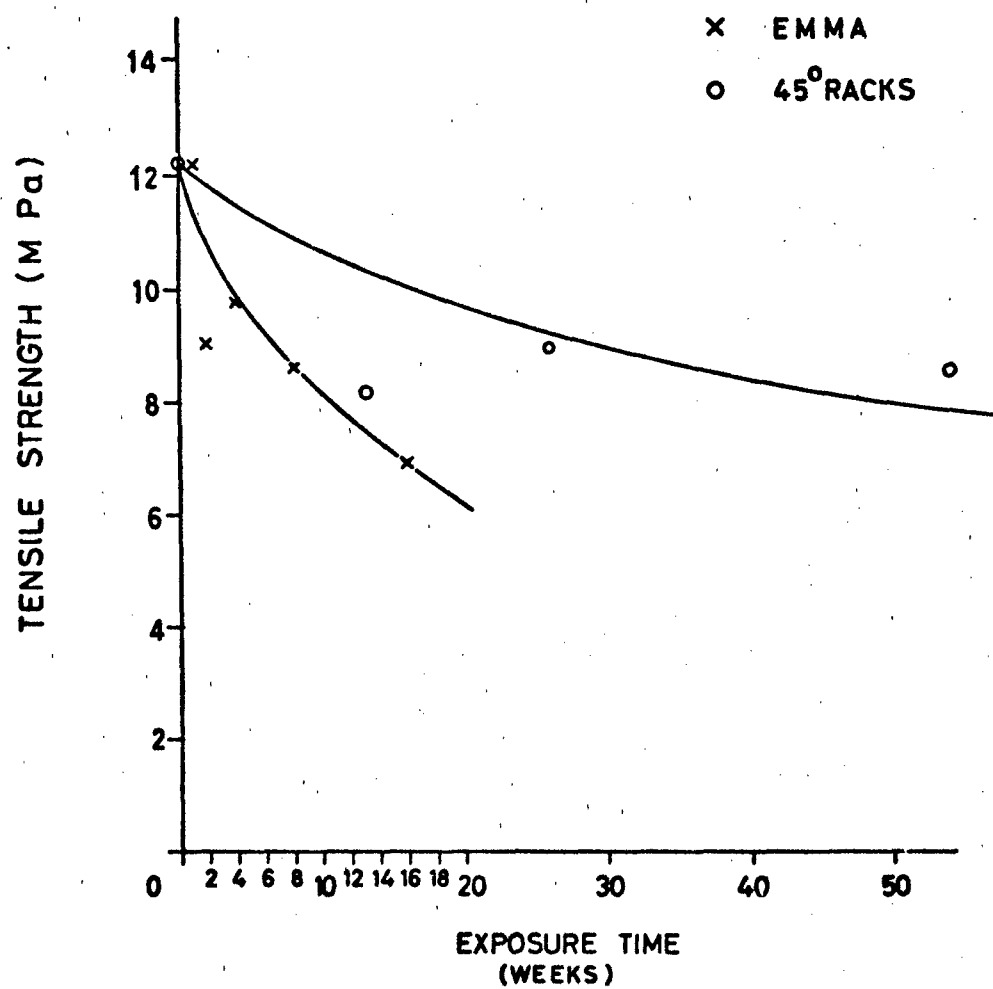


FIG 2 TENSILE STRENGTH AT BREAK OF L D POLYETHYLENE

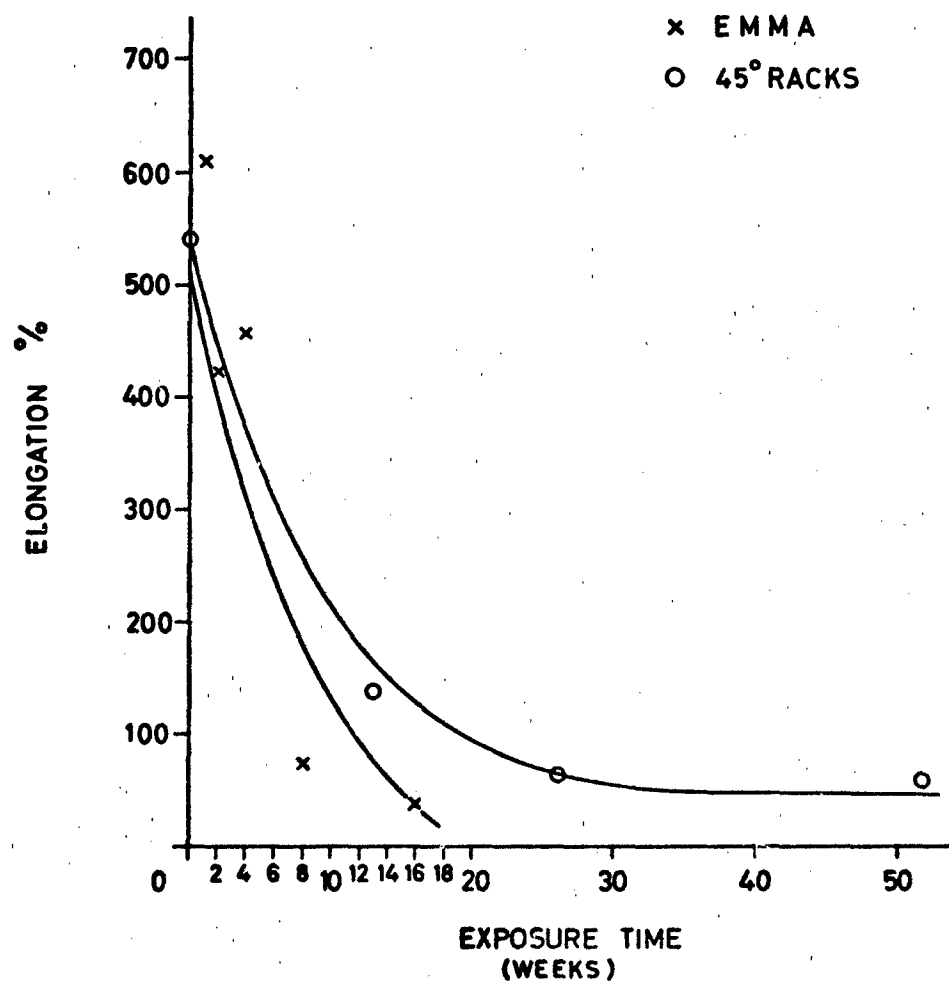


FIG 3 ELONGATION AT BREAK OF L D POLYETHYLENE

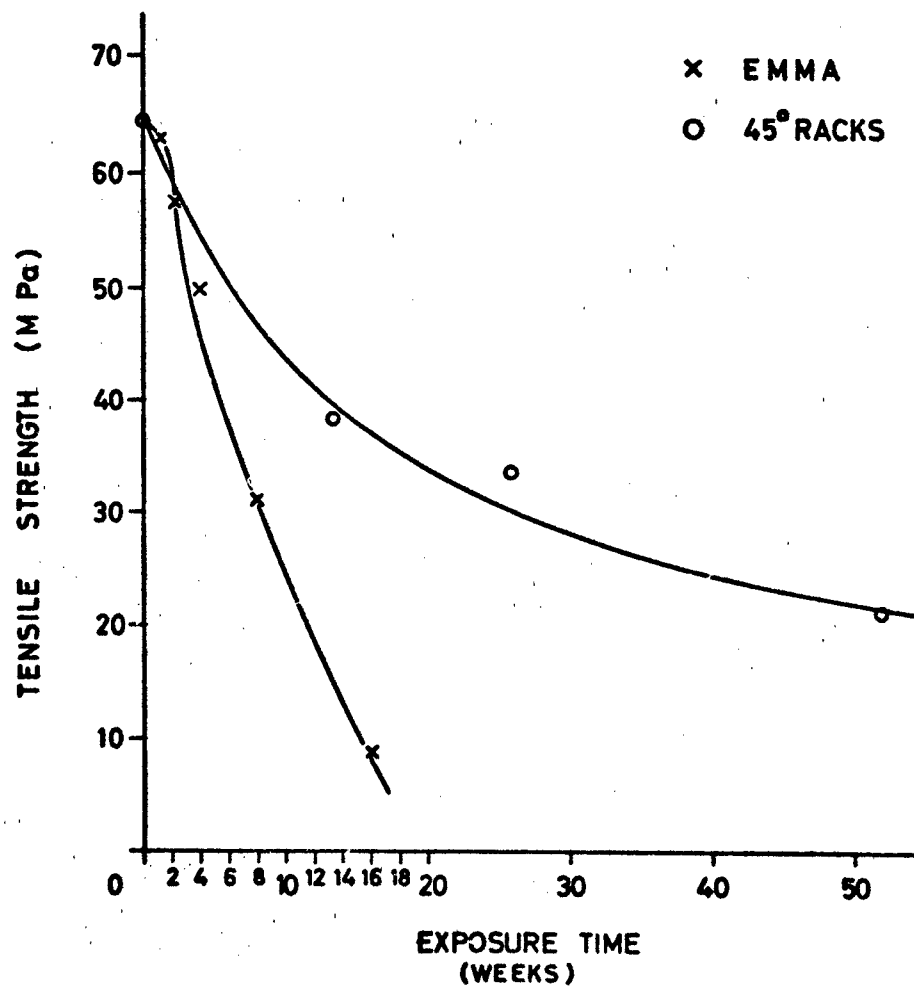


FIG 4 TENSTILE STRENGTH AT BREAK OF ACETAL COPOLYMER

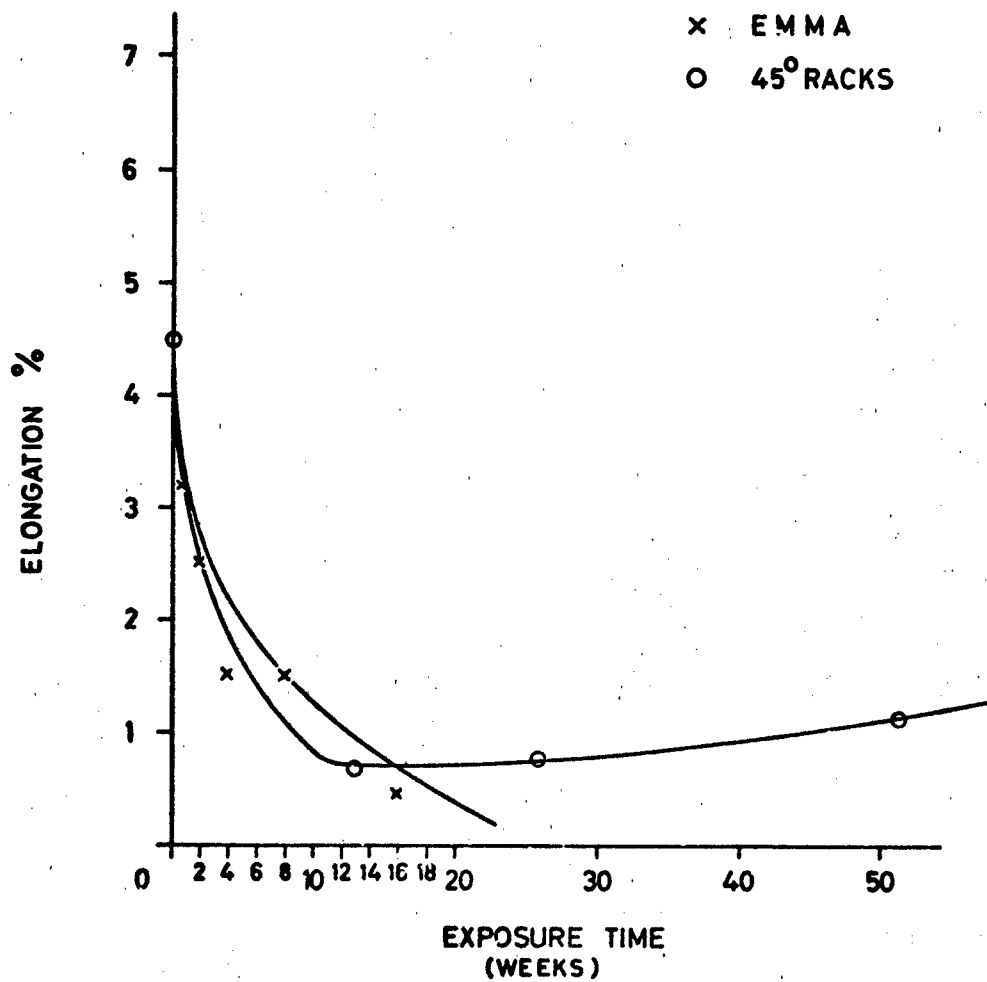


FIG 5 ELONGATION AT BREAK OF ACETAL COPOLYMER

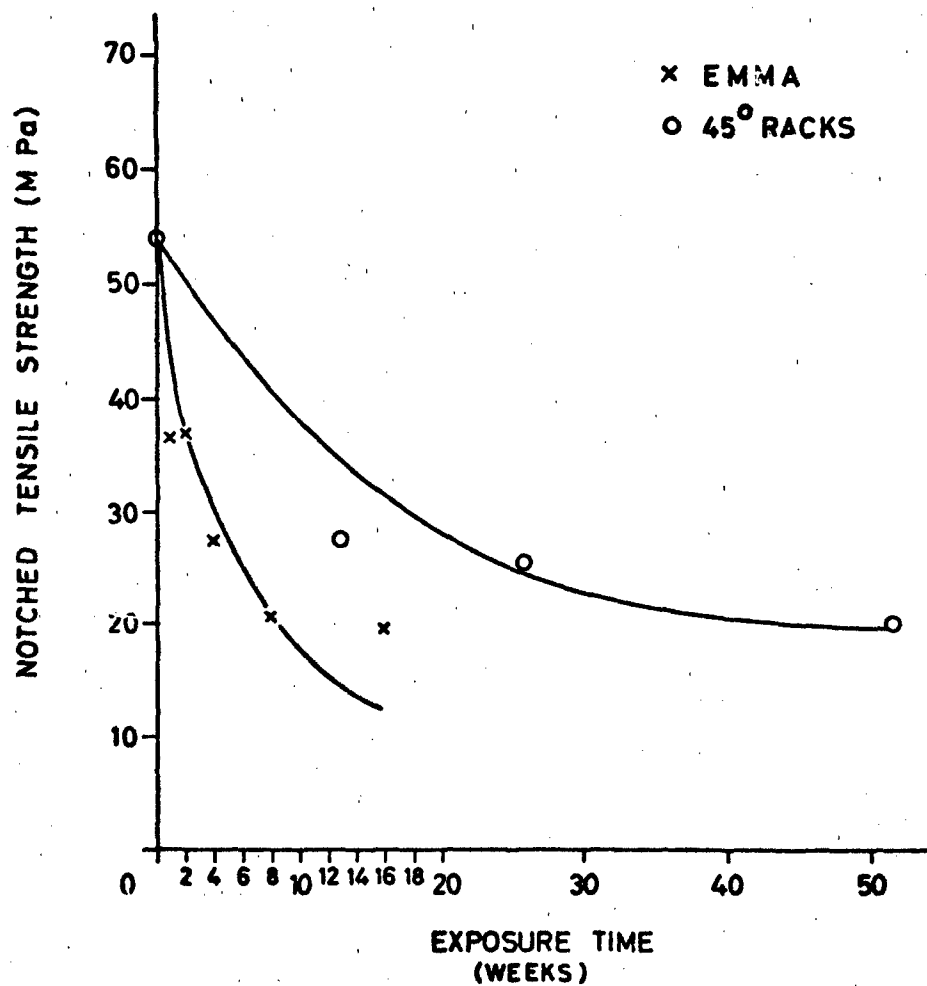


FIG 6 NOTCHED TENSILE STRENGTH OF ACETAL COPOLYMER

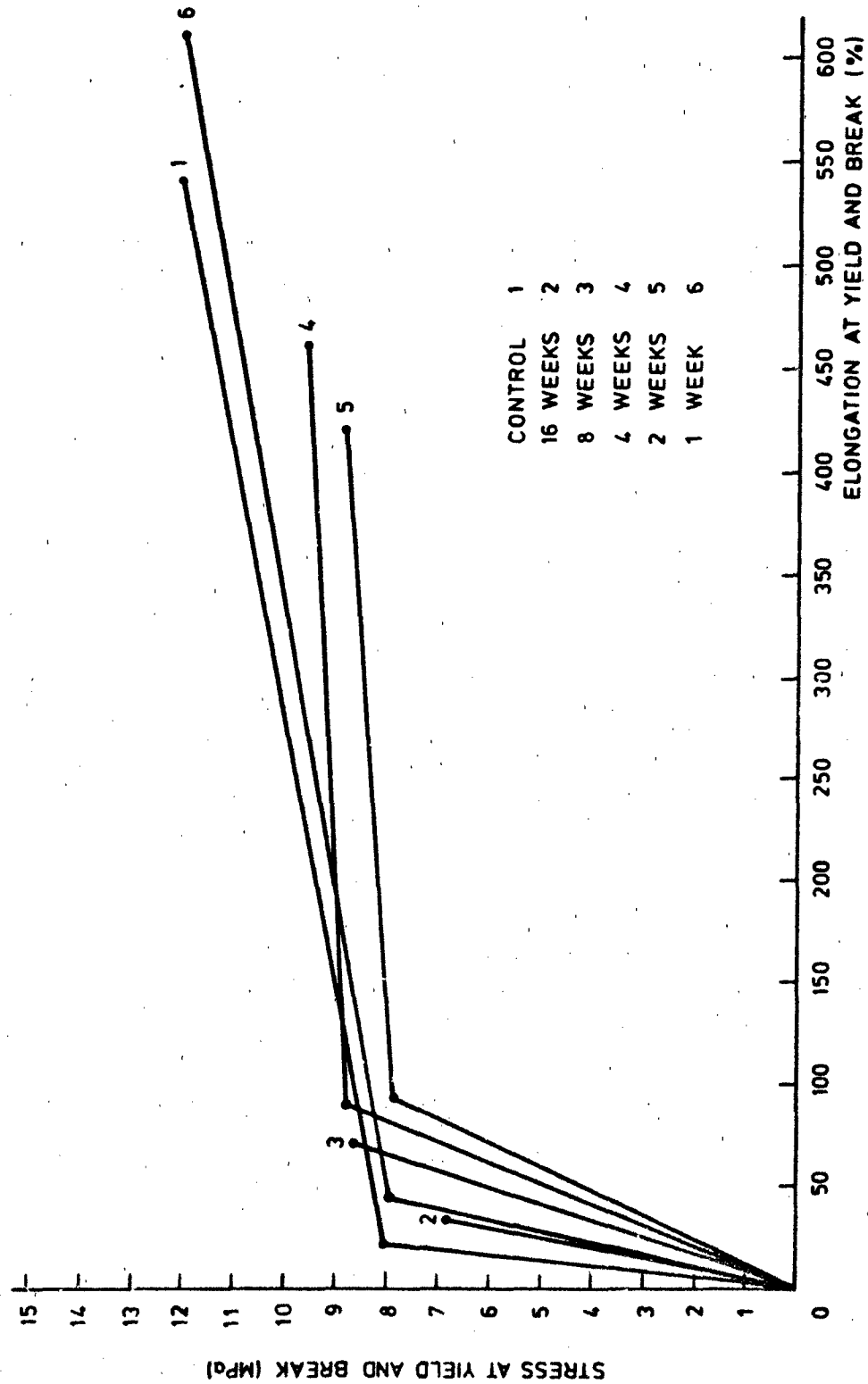


FIG.7 TENSILE AND ELONGATION BEHAVIOUR OF LD POLYETHYLENE EXPOSED ON EMMA

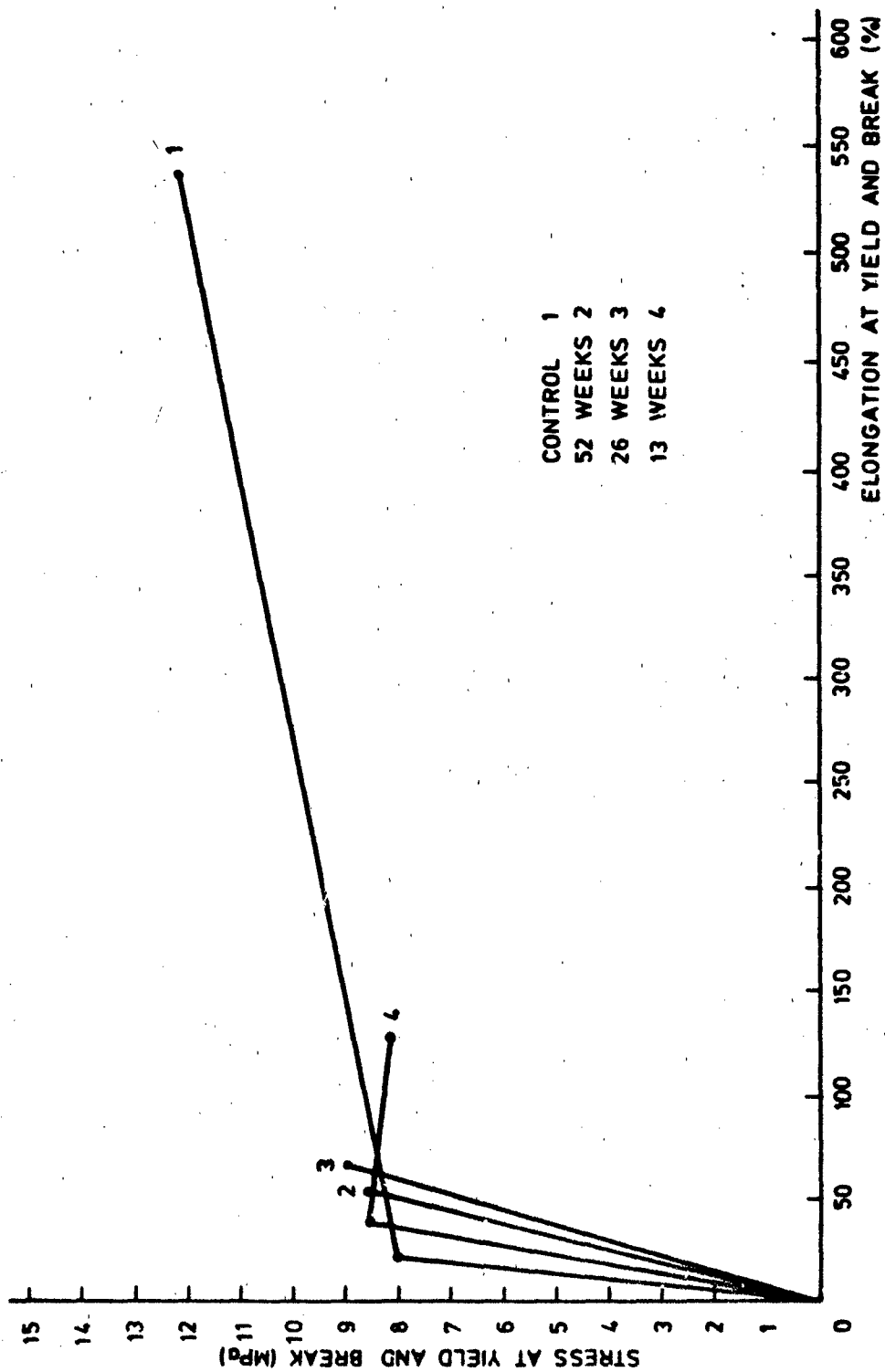


FIG.8 TENSILE AND ELONGATION BEHAVIOUR OF LD POLYETHYLENE EXPOSED ON 45° RACKS

REPORT DOCUMENTATION PAGE

(Notes on completion overleaf)

Overall security classification of sheet Unlimited

(As far as possible this sheet should contain only unclassified information. If it is necessary to enter classified information, the box concerned must be marked to indicate the classification eg (R), (C) or (S).

1. DRIC Reference (if known)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification Utd
5. Originator's Code (if known) 7281400E	6. Originator (Corporate Author) Name and Location Propellants, Explosives and Rocket Motor Establishment Waltham Abbey Essex England		
5a. Sponsoring Agency's Code (if known)	6a. Sponsoring Agency (Contract Authority) Name and Location		
7. Title WEATHERING OF PLASTICS MATERIALS IN THE TROPICS 3 THE EVALUATION OF A SOLAR RADIATION CONCENTRATION DEVICE (EMMA) AS A MEANS OF ACCELERATING THE WEATHERING OF PLASTICS			
7a. Title in Foreign Language (in the case of translations)			
7b. Presented at (for conference papers). Title, place and date of conference			
8. Author 1. Surname, initials Procurement Executive, Ministry of Defence	9a. Author 2 Federation Joint Committee on the Behaviour of Plastics	9b. Authors 3, 4... Materials under Tropical Conditions	10. Date pp 6.1979 32
11. Contract Number	12. Period	13. Project	14. Other References
15. Distribution statement			
Descriptors (or keywords) Weathering, Artificial weathering tests, Accelerated tests, EMMA, Solar radiation, Acetal resins, Polyethylene (TEST)			
Abstract This report gives details of a trial in Phoenix comparing the rate of natural weathering with that for exposure on EMMA - a device which increases the intensity of solar radiation. The materials exposed were low density polyethylene and poly-acetal. An acceleration factor of about two was found for both materials.			